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EXPERIMENTAL EVALUATION OF ATMOSPHERIC EFFECTS ON RADIOMETRIC MEASUREMENTS USING THE EREP OF SKYLAB. (EPN No. 439)

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EXPERIMENTAL EVALUATION OF ATMOSPHERIC EFFECTS ON RADIOMETRIC MEASUREMENTS USING THE EREP OF SKYLAB

1. PROGRAM SUMMARY

In this study, a systematic experimental program has been undertaken using the EREP of Skylab to evaluate experimentally the effect of the atmosphere on remote sensing measurements made from orbital altitudes and to investigate the possibility of deriving useful semiempirical techniques to correct for such effects. The basic data source is the high-resolution (approximately 260 feet) multispectral scanner (S192) providing calibrated quantitative radiometric measurements in 13 bands in the visible and near-infrared portions of the spectrum, and covering the spectral intervals most extensively used in aircraft surveys of earth resources. Correlating radiometric data is available from the short wave length (SWL) S191 interferometric spectrometer at considerably higher spectral resolution. Information concerning the radiative properties of the atmosphere and hence its effect in remote sensing analysis is potentially available from the corresponding S191 long wavelength (LWL) data. The nature of the surface target is documented utilizing S190A and S190B imagery to provide an indication of the target surface homogeneity, topography, minerology, and morphology. In addition, this imagery provides the base map upon which to portray the area pixels sensed by the satellite radiometers and employed in the theoretical analysis.

The analysis has been augmented by an extensive ground-truth program at the two selected test sites: the Salton Sea Desert and the Great Salt Lake Desert. Ground-truth includes _in situ_ measurements of hemispheric and directional surface reflectance and solar total and diffuse intensities.

The measured reflected solar intensity is calculated in the following manner:

> Utilizing a simple surface-atmosphere geophysical model and the Skylab EREP S192 channel spectral response characteristics, the theoretical satellite-measured S192 radiances can be calculated. The surface is assumed to be a Lambert reflector (usually a good assumption at high solar elevation angles) and the atmosphere diffuse-reflected solar radiation is assumed to be a linear function of surface reflectance.

Repeating the calculation without weighting by bandpass simulates the type of measurement given by the S191 instrument. Computations of atmospheric transmissivities require a thorough knowledge of the abundance and vertical distribution of radiatively active gases (primarily O_3, O_2, H_2O, and CO_2 in this spectral region) in addition to temperature structure and aerosol content. This information is input in the form of a finite number of model atmospheres. Combining the real data and the theoretical calculation allows the atmospheric effect at each wavelength of interest to be evaluated and corrected for in the data. These corrections may be expressed in terms of equivalent surface reflectivities and, therefore, the true surface reflectance spectrums (as would be measured by a low flying aircraft) is potentially retrievable. It is suggested that evaluation of the atmospheric effect is a fundamental precursor to surface type analysis by spectral identification. If, in fact, the total atmospheric effect on earth resources measurements can be determined with a limited number of atmospheric parameters, adequately prescribed by synoptic and climatological events, the use of satellite data in earth resources surveys over remote regions would be greatly enhanced.

2. PRESENT PROGRAM STATUS

As specified in the original contract, the program summarized in the previous section is to be computed on or before 30 June 1974.

The analysis to be performed in this study requires digital values of S192 aperture radiances as the primary data set. Due to processing difficulties, we have been informed that data will be available at the earliest in late June. Simulated S192 radiances from the ERAP ground truth flyover of the Salton Sea region, will not be available until January, 1975. It will therefore, not be possible to complete this study within the scheduled time period ending 30 June 1974. The Technical Monitor (or PIMO) have been notified of this problem. We have been assured verbally that plans are underway for the extension of the contract period to beyond the current 30 June termination date.

At the present time (7 May 1974), the status of the program outlined in the previous section may best be characterized as being in a holding pattern. Delays in the receipt of processed digital data and difficulties with data which has been received (such as the scheduled reprocessing of S191 data.), have made application of a serious analysis program necessarily intermittent. Therefore, the following tasks have been adapted within the interim period while awaiting data receipt:

a) Imagery (S190A and S190B) continues to be reviewed for pertinent features and catalogued as it is received.

b) Interferometric (S191) data will be analyzed on a case basis using tabulations as a first approach as reprocessed data is received. Digital tapes will be employed for further analysis when experience dictates that it is suitably corrected. Preliminary information to be gained from the S191 data includes the target reflectance isotropy and a rough characterization of atmospheric structure over the target.

c) Data from the S192 multispectral scanner is expected in the near future.

d) Development of the theoretical analysis will proceed on a schedule coordinated with the schedule of data receipt so that all development, programming, and preliminary study is completed and received data may be analyzed.

The following sections describe, respectively; the data received as of this time, progress during the reporting period, and the present status of the theoretical analysis.

3. SENSOR SUMMARY

The following subsections describe the data received to date and discuss any problems encountered.

3.1 S190A Imagery

Pass	Magazine	Frame	Description
2	01/02	113/120	1 ea. Pos/1 ea. neg.
	03/04	129/126	
	05/06	113/120	
5	07/12	001/010	1 ea. Pos/1 ea. neg.
20	25/26	186/189	1 ea. Pos/1 ea. neg.
	28/30	186/189	
37	37/38	140/150	1 ea. Pos/1 ea. neg
	39/40	140/150	1 ea. Pos
	41/42	140/150	1 ea. Pos/1 ea. neg.
39	37/38	196/205	
	39/40	196/205	(Same)
	41/42	195/205	
43	37/38	329/335	
	39/40	329/335	(Same)
	41/42	329/335	
45	43/44	052/058	
	45/46	052/058	(Same
	47/48	052/058	

3.2 S190B Imagery

Pass	Magazine	Frame	Description
5	81	001/014	1 each Pos.
20	85	002/005	1 each Pos.
37	86	321/333	1 each Pos.
39	88	010/017	1 each Pos.
43	87	110/116	1 each Pos.
45	88	093/101	1 each Pos.

3.3 S191 Digital Tapes

These data were received in two batches: (a) initial processing (I) received prior to letter of 23 April 1974 describing problems in both SWL and LWL data; (b) reprocessed data (R) received in second go-round.

Pass	Output Tape No.	Remark (I or R)
2	909166/909167	I
	909344/909345	I
5	906332/906333	I
12	906225/906/226	I
	916219/916220	R
20	906367/906368	I
	917747/917751	R
37	906400/906401	I
	916694/916695	R
	918136/918137	R
39	906402/906403	I
	916689/916617	R
43	907217/907219	I
	916692/916693	R

(Some of these tapes were received after the reporting period, but are included for completeness.) Accompanying tabulations have been received corresponding to the digitized GMT segments. Naturally, only the reprocessed data will be analyzed.

3.4 S192

No digital values of S192 aperture radiances have been received either in tabulation or CCT form. Screening film (generally channels 2-7-11 or 2-9-11) has been received from each pass and reviewed.

This group cooperated with Mr. James C. Barnes (Principal Investigator, EREP Investigation No. 420) in study ing an S192 digital tape received for his work. Difficulties in understanding the processed data and seeming inconsistencies were cataloged.

3.5 ERAP Aircraft Ground Truth - Simulated S192 Radiances

Viewing film from the 24 channel multispectral scanner (MSS) from ERAP Mission 238, Flight 17 for Site 27 (Salton Sea) underflying EREP Pass 2 on 2 June 1973 was received and reviewed. Digital data simulating S192 EREP output (ERAP Product No. A071-4) for five area element was ordered for this study on 8 January 1974.

4. PROGRESS DURING THE REPORTING PERIOD

4.1 Surface Characteristics Documentation - S190A and S190B Imagery

Study of S190A and S190B imagery prompted a decision to concentrate on two specific test areas:

#547119 Salton Sea - Sonoran Desert

#547220 Great Salt Lake - Bonneville Salt Flats

EREP test site surface characteristics for this study have been documented in detail in the following manner:

4.1.1 Base Map Preparation - General Base

Maps were prepared to appropriate scale from S190B earth terrain photography. Site 547119 was prepared to a scale of 1:250,000 from a color infrared transparency, frame number 112 of magazine 87. Site 547220 was prepared to a scale of 1:500,000 from a color aerial transparency, frame number 007 of magazine 81. Selection of these particular data products was based on maximum enhancement of surface features. These exhibits effectively demonstrate the relative surface homogeneity of the particular digital data segments which have been selected for further analysis. (Section 4.2)

4.1.2 Mineralogical - Topographical Survey - Overlays

Map overlays were prepared to scale which delineate the surface distribution of mineralogical species and relate regions of relatively uniform topography. A specific knowledge of these two factors is essential to successful implementation of the theoretical analysis.

Mineralogical information has been extracted from the appropriate USGS, state, and local maps which are available. In addition, when necessary, personal consultation with knowledgeable sources (e.g., University of Utah, Geology Department) was correlated with the published data available.

A complete geological analysis report was prepared for each site to accompany and explain the map overlays. These reports discuss surface mineralogy, uniformity, and morphology in addition to containing a key to the overlay.

A fundamental result expected of this documentation will be increased capacity to correctly identify the nature of the mineral species within the instrument field of view, and hence to choose an appropriate spectral reflectance curve.

4.1.3 Orbital Overlays

Base map overlays to appropriate scale were prepared tracing the S192 field of view for each ordered orbital pass and test site. Currently, these are passes 2 and 43 for the Salton Sea area and passes 5 and 39 for the Salt Lake - Bonneville region. Additionally, a similar overlay was prepared to cover the Earth Resources Aircraft Program ground truth flight for the Salton Sea region, Mission 238, Flight 17. The format for these overlays is identical, plotting GMT vs. position in the test site area from the appropriate accompanying field of view and navigation and guidance documentation. Using these tools, the specific digital data segment area elemets chosen for extended analysis will be portrayed against its mineralogical, topographical, and surface base maps.

4.1.4 Digital Radiances

Upon receipt, where feasible, digital radiances will be portrayed in similar format, possibly employing an intensity level contour map to delineate the effect of varying surface characteristics.

4.2 Selection of S192 Data

Target selection criteria of area homogeneity and "flatness" have been applied to S192 screening film and S190A and S190B imagery to select digital GMT segments of S192 radiances in the two primary test sites for further analysis. These are:

<u>EREP Pass 2 (2 June 1973)</u>

GMT Time Interval:	200822.0 GMT
Location:	33.5N, 116.0W (Salton Sea)
Channels:	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

4.2 Selection of S192 Data

EREP Pass 5 (5 June 1973)

1. Segment A

GMT Time Interval:	175737.0 - 175742.0 GMT
Location:	40.7N, 113.8W (Bonneville Salt Flat)
Channels:	2,3,4,5,6,7,8,9,10,11,12

2. Segment B

GMT Time Interval:	175810.0 - 175814.0 GMT
Location:	39.3N, 11.4W (Wasach Range)
Channels:	2,3,4,5,6,7,8,9,10,11,12

EREP Pass 39 (13 September 1973)

1. Segment A

GMT Time Interval:	193404.3 - 193407.0 GMT
Location:	40.7N, 113.8W (Bonneville Salt Flat)
Channels:	2,3,4,5,6,7,8,9,10,11,12

2. Segment B

GMT Time Interval:	193421.7 - 193424.2 GMT
Location:	41.25N, 112.6W (Great Salt Lake)
Channels:	2,3,4,5,6,7,8,9,10,11,12

3. Segment C

GMT Time Interval:	193416.8 - 193418.9 GMT
Location:	41.1N, 113.0W (Desert)
Channels:	2,3,4,5,6,7,8,9,10,11,12

EREP Pass 43 (15 September 1973)

1. Segment A

GMT Time Interval:	180504.7 - 180505.9 GMT
Location:	33.3N, 115.9W (Salton Sea)
Channels:	2,3,4,5,6,7,8,9,10,11,12

2. Segment B

GMT Time Interval:	180501.5 - 180503.7 GMT
Location:	33.2N, 116.1W (Desert)
Channels:	2,3,4,5,6,7,8,9,10,11,12

Availability of ground truth was a factor in the selection of Passes 2 and 5. Aircraft under flight (ERAP Mission 238, Flight 27) is available for Pass 2 while surface measurements of atmospheric optical depth and surface reflectivity are available for Pass 5. Collection of ground truth for this latter pass was not within the requested Bonneville Salt Flat region, but is contiguous to the Great Salt Lake. An additional CCT digital segment for the GMT time of the ground truth site overpass (EREP Pass 5, Ground Track 34, Rev. 318/319; GMT 156:17:57:45) of the S192 GMT correlated aperture radiances was, therefore, requested. Preliminary analysis of the collected ground truth data was performed.

4.3 Theoretical Analysis

With little data to work with, the bulk of the effort has been applied to formulating the theoretical analysis to be employed. The following approach has been adapted for calculating theoretical S191 and S192 aperture radiances based on a finite set of geophysical parameters.

The spectral character of the measured reflected solar radiation will be dependent upon three basic system parameters: (1) the atmosphere (characterized by its transmissivity and scattering properties); (2) the surface (characterized by its spectral reflectance); and (3) the spectral response of the satellite sensor (defined by its channel spectral responsivity). A simple surface atmosphere model is employed, assuming Lambertian reflection at the surface and allowing for both absorption and scattering by atmospheric gases and aerosols. The atmosphere diffuse-reflected solar radiation is assumed to be a linear function of surface reflectance (Griggs, 1973). Computations of the atmospheric transmissivity requires a thorough knowledge of the abundance and vertical distribution of radiatively active gases (primarily O_3, O_2, H_2O, and CO_2 in this spectral region) in addition to temperature structure and aerosol content. This information is input in the form of a finite number of atmospheric models. The actual transmittance values are calculated by the LOWTRAN 2 computer code (Selby and McClatchey, 1972). Theoretical values for the S192 channel radiances are calculable from the expression:

$$R^i\ (a,b,c) = \frac{1}{\pi}\int_{\lambda_1^i}^{\lambda_2^i} I(\lambda)\ \phi^i(\lambda)\ [T_\theta\ (\lambda)\ r\ (\lambda)\ \sin\theta\ (aT_Z(\lambda) - b) + cJ_\theta\ (\lambda,r)]\ d\lambda$$

Radiances at zero air mass (such as are measured by aircraft ground truth) are similarly calculated by assigning unit transmissivity to the atmosphere on the exit path. The difference between the theoretical radiance and the zero air mass radiance is the atmospheric correction for the channel.

where: (Sources and references in brackets)

1) Superscript i refers to a particular S192 channel with wavelength limits specified by $(\lambda_1^i, \lambda_2^i)$: $i = 1,2,3, \ldots, 13$.

2) Parameters (a,b,c) identify the calculated intensity R^i in the following manner:

   $R^i(1,0,1)$ = theoretical S192 channel radiance

   $R^i(0,-1,0)$ = theoretical "zero air mass" radiance

   $R^i(1,1,1) = R^i(1,0,1) - R^i(0,-1,0)$ = atmospheric correction

3) $I(\lambda)$ = solar irradiance spectrum (watts $m^{-2}\ \mu m^{-1}$) [Thekaekara, 1970]

4) $\phi^i(\lambda)$ = S192 $i^{\underline{th}}$ channel spectral responsivity [NASA-JSC, 1973]

5) θ = solar elevation angle for the particular test site geometry

6) $T_\theta(\lambda)$ = atmospheric transmissivity from surface to space at angle θ

   $T_Z(\lambda)$ = zenith atmospheric transmissivity [Selby and McClatchey, 1972]

7) $r(\lambda)$ = surface reflectance spectrum [ground truth and/or Hunt et al, 1970-1974]

8) $J_\theta(\lambda,r)$ = atmospheric diffuse reflectivity at angle θ and for surface reflectance r [Fraser, 1973 and Plass and Kattawar, 1968]

These computations provide not only for immediate magnitude comparison with actual S192 radiances, but allow interchannel (differential) spectral effects to be evaluated.

Simulated S191 data may be obtained by evaluating only the integrand as a function of wavelength while assigning the response function an effective value of 1.0 at all wavelengths.

The most difficult parameter to arrive at for the analysis appears to be the surface reflectance spectrum. In the Great Salt Lake test site (547220) ground truth effort, measurements of the surface reflectance spectrum for bidirectional and hemispheric reflectance indicate that the test site surface is non-Lambertian. For a Lambert reflector, the ratio of hemispheric to bidirectional reflectance should be π. For the desert target surface, this quantity appears to be approximately 1.25 (i.e., too low). This indicates that there is an appreciable specular component of reflection. If our targets are indeed not Lambert reflectors, the final theoretical analysis must be amended. It is expected that this assumption is testable by following the variation of S191 radiances for targets aquired and maintained along the orbital track.

A comprehensive library of reflectance curves has been assembled based on the work of Salisbury and Hunt at the Terrestrial Sciences Laboratory of the Air Force Cambridge Research Laboratories (Hunt, et al., 1970-1973). They have studied spectra of more than 200 mineral and 150 rock samples to determine the origin of spectral features and to assess the utility of the visible and near infrared region for remote sensing of rock type, and have isolated the drawbacks associated with attempting to categorize the surface reflectance spectrum of a mixed mineralogical species on the basis of pure sample measurements (J. W. Salisbury, personal communication). It is believed that their results and assessment of the problem will aid markedly in a realistic assignment of the most correct spectral reflectance curve based on the geological analysis (Section 2.2). Implementation of these considerations at the present will consist of isolating the surface species within the field of view with the most outstanding spectral reflectance features, selecting its spectral reflectance curve, masking it by an appropriate mixing factor, and averaging the continuous curve for each S192 channel segment by convoluting with the appropriate channel response function.

It is hoped that this approach will provide a realistic $r(\lambda)$. If this approach is not feasible, theoretical calculations may be generated for a family of constant reflectance curves between zero and unity and the actual reflectance curve retrieved by plotting the acquired data.

5. Future Plans

Analysis will commence immediately upon receipt of the first S192 CCT's. Travel to NASA-GSFC, Greenbelt, Maryland, is anticipated during the next reporting period for the purpose of conferring with Dr. Robert Fraser on the use of his path radiance calculations.

6. Significant Results

There are no identifiable, significant results to be reported at this date.

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